Fermilab International Linear Collider R&D Plan for FY06

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Goals:

Fermilab ILC R&D is focused on addressing the key ILC design and technical issues, cost reduction and US industrial involvement in ILC. These goals are aimed towards the development of the ILC Technical Design Report. The R&D goals are designed to establish the viability of technical components addressing TRC Ranked R&D goals, costs, engineering designs to enable "early" decision (by 2010) and to position the US (and Fermilab) to host the ILC.

The main thrust of the Fermilab ILC R&D is to establish US technical capabilities in the Superconducting Radio Frequency Cavity and Cryomodule technology. The main goals described in detail in the proposal are

1) Cavity technology development in the US to routinely achieve $\geq$ 35 MV/m and Q ~0.5-1e10,
2) ILC Cryomodule design and fabrication,
3) Fully tested basic building blocks of the Main Linac
4) Accelerator design issues in the Main Linac, Damping Ring and Machine Detector Interface
5) Development of an ILC site near Fermilab.

While focused on the long term goals for ILC design and construction, Fermilab will also work with the GDE in development of the Reference Design Report, taking responsibilities for the chapters on Main Linac and US Site, by the end of FY06.

1.0 Introduction

The U.S. Department of Energy has expressed its interest in the possibility of hosting a linear collider, at Fermilab. The Fermilab Long Range Plan establishes the ILC as the primary goal, with a world-leading neutrino program if the ILC were delayed or constructed elsewhere. Fermilab ILC R&D program is aligned with US aspirations for the future leader in HEP. Fermilab is committed to a leadership role in the ILC R&D program and to preparing to host the ILC when/if that decision comes. Fermilab Director Pier Oddone in recent presentations has stated that the Energy Frontier ILC is the highest priority initiative for the laboratory. Fermilab's goals are to 1) establish the viability of all technical components, costs, engineering designs, and management structures to enable "early" decision (by 2010), 2) position US (and Fermilab) to host the ILC and 3) position US (and Fermilab) to play major roles in the detector development and physics analysis.

The ILC R&D at Fermilab, has its main focus on the Main Linac and Conventional Facility. Fermilab in discussion with ILC Americas organization has expressed interest in providing leadership role in Accelerator Physics, Cryomodule and Cryogenic design, the Cryomodule test facility, Instrumentation and Controls, Conventional facility (site development) and ILC management. We would also participate with our broad expertise in the development of RF power, Source, Damping Ring, Beam Delivery, IR and Machine Detector Interface. Fermilab ILC R&D strategy is to provide leadership of the America's regional effort in development of the SCRF technology base for ILC. It is imperative to establish US-based capability in the fabrication of high gradient superconducting accelerating structures if the US is to compete to host. Significant U.S. SCRF development and fabrication experience at: Argonne, Cornell, Fermilab, Jefferson Lab, Los Alamos, Michigan State, but at gradients significantly below 35 MV/m. Fermilab is establishing facilities to fabricate and test US-produced ILC cavities and cryomodules with national and international partners. This facility could also be used for the integrated system test of the main linac with an ILC-like beam.

Fermilab ILC R&D over the next ~18 months will be focused on developing the SRF capabilities with domestic and international partners. We will also work with the GDE in completion of the ILC Reference Design Report (RDR). We plan to contribute to the overall document, parameters, design and cost estimate with a lead role in the Main Linac including cryogenics and civil studies chapters of the RDR.

In FY05 following the ILC technology recommendation, Fermilab ILC R&D efforts started to focus on the Superconducting Radio Frequency Technology development for the Main Linac. Fermilab had made significant contributions in both the X-Band and L-Band ILC design in close collaboration with SLAC and DESY respectively. Fermilab has worked closely with DESY staff to design vertical test inserts for cavities, input power couplers and 2K refrigeration system for the vertical tests. Fermilab staff has been closely involved with the commissioning of the TTF superconducting linac. During the U.S. Options Study, Fermilab made major contributions to the refrigeration system and the site layout, including cost estimates. Fermilab has helped in designing and building modulators and cryogenic systems for L-Band test facility (TTF) at DESY. The Fermilab RF engineering design team has produced a several X-Band structures that could meet the NLC design goals.

Fermilab's International Linear Collider R&D plan for FY06 is continuation of our efforts in FY05. The main focus of the R&D effort has been in developing the US expertise in fabricating Superconducting Radio Frequency Cavities and Cryomodule for the ILC. It is anticipated that Fermilab ILC R&D will get integrated into the GDE. This ILC R&D will be coordinated with the GDE and the ILC-Americas director.

Fermilab is co-ordinating the ILC SRF development with the SMTF (The superconducting Module and Test Facility). This is a multilaboratory collaboration with substantial SRF expertise and key SRF facilities, both of which need fostering at this early stage to make strong contributions to the ILC needs.

The outline of ILC Accelerator R&D activities is

- Development of the Reference Design Report
- ILC Accelerator Physics and Technology R&D
  - Accelerator Physics
    - Linac design, Emittance preservation simulation
    - Vibration studies and its impact on Emittance preservation
    - Damping Ring design, Instability calculations
    - Collimation and Machine detector interface
    - Electron source
  - Accelerator Technology
    - Develop and execute a procedure to establish processing parameters that reliably provide > 35 MV/m cavities.
    - ILC (4th Generation) SRF cryomodule design, prototype, assembly and tests, including beam tests:
    - Cryogenic system and distribution
    - RF power for the Linac
    - Electron RF Source Development

- Civil: Near Fermilab site, Reference Site design, Conventional Facility
- Collaboration & Outreach

((*These R&D will support the development of baseline design for the Reference Design Report. But our focus is on TDR as this would require significant effort in engineering, cost reduction, schedule, reliability and industrialization. We consider most of the work being done at Fermilab for ILC is towards developing US laboratory and industrial infrastructure to host ILC in US. , and We put all the Fermilab ILC R&D in priority 1 as defined by GDE. We comment on possible other interpretation by GDE throughout this document.*)

2.0 Development of the Reference Design Report

Goals and Motivation: Fermilab scientific and engineering staff will work with the ILC GDE for the next 18 months in development of the Reference Design Report (RDR). Fermilab will write the Main Linac and US site chapters in the RDR. We also plan to actively participate in the full document.

Milestone: 1. Outline of the RDR by the end of Snowmass. 2. Finalize RDR by end of FY06.

Fermilab ILC R&D is focused towards development of the ILC Technical Design Report (TDR). In the mean time Fermilab scientific and engineering staff will also work with the ILC GDE for the next 18 months in development of the Reference Design Report (RDR). It is anticipated that this document will be developed now through the end of 2006. The plan is to define the ILC baseline configuration by the end of the Snowmass workshop (Aug 05) with a goal to have the Baseline Configuration Document (BCD) by the end of 2005. The ILC baseline configuration will be put under configuration control and will be used to develop the ILC RDR by the end of 2006. The TDR is expected to be developed by the end of 2008-2009.

Fermilab has proposed to participate in the overall document preparation with primary focus on ILC parameter development, Main Linac, Site and Conventional facility and costing. We are proposing to take a secondary role in Damping Ring and the Machine Detector Interface. We are also growing in the area of instrumentation and controls for the ILC. Fermilab is rapidly developing a superconducting RF capability for the main linac design and development for the ILC. Fermilab is also co-ordinating SMTF activities towards an early ramp-up of US SRF ILC capabilities. The Civil group at Fermilab is playing a central role in developing methods for understanding the site and the interplay with the design. Plans are being developed to build a strong e^+e^- accelerator physics group at Fermilab for the ILC.

In the next four sections we describe a short summary of specific work we plan to undertake at Fermilab. This will include design and simulation of the Main Linac, Damping Ring and Machine Detector Interface. The SRF R&D for Main Linac includes achieving cavity performance of 35 MV/m, establishing US leadership in SRF technology, cavity and cryomodule fabrication, and testing of the Main Linac building blocks with beam. These efforts are all designed to answer crucial ILC R&D questions. Fermilab with its considerable experience in superconducting technology development and fabrication of large devices and cryogenic will work toward the cost reduction and performance enhancement of these components. We also propose to work with industries in technology transfer and the development of industrial capability to support the ILC construction. Fermilab is also working on the site and conventional facility development. Overall from the cost point of view Fermilab is involved in more than 70% of the ILC.

Deliverable: Chapters on Main Linac and US Site Development

(*We consider most of the work being done at Fermilab for ILC is towards the baseline design for the Reference Design Report and TDR, hence we put them in priority 1 as defined by GDE.*)

2.1 Accelerator Physics

Fermilab is participating in three major topics for the Linear Collider accelerator physics. We plan to continue our participation in these areas for next several years with the main focus on the Main Linac. This effort has been growing at Fermilab in last two years. We plan to increase this effort in FY06 as resources are becoming free from the Run-II Upgrade and other Fermilab projects.

Goals: The goal of accelerator physics activities are to work on the ILC design.

2.1.1 ILC Main Linac lattice and Low Emittance Transport (LET) studies

Fermilab will participate in the ILC linac design. There are several engineering issues that will require accelerator physicists and engineering staff to work together in the design of the cavity string, support etc. There are main linac lattice issues that have to deal with the placement of the quadrupole and BPM in the cryomodule. The RF distribution, wakefield, higher order modes, and their effect on the beam quality needs to be studied. The transport of a low emittance beam from the exit of the damping ring to IP will be one of the challenges for achieving the design luminosity of the linear collider. Fermilab, in collaboration with SLAC and DESY, is developing tools to study the preservation of emittance in the main linac.

We have been working on the preservation of the transverse beam emittance in the main Linac of the ILC, which is necessary in order to achieve the desired collision luminosity. We have performed simulation studies based on LInear Accelerator Research (LIAR) code interfaced with MATLAB on different aspects of this problem. The main goal is to understand the various sources of the emittance dilution in the main linac and devise means to minimize it. We have carried out simulations on the US ColdLC Lattice (a constant beta lattice with 60^0 phase advance, similar to the TESLA TDR design) under nominal conditions including realistic misalignment tolerances and wakefields. We have studied the contributions of the various sources of emittance dilution like quadrupole or structure misalignments, structure pitches, quadrupole rotation etc. to the total emittance dilution. The conventional survey and alignment techniques will not be sufficient to meet the required emittance dilution budget for the ILC and hence new and improved beam based alignment techniques are needed. To facilitate that, we have compared the performance of the two different beam based steering algorithms: Dispersion Free (DF) steering and the Flat (or one-to-one) steering in terms of the emittance dilution. On the basis of these studies, we have found that DF steering provides significantly better results than Flat steering. The sensitivity of the emittance dilution for both the steering techniques is compared for the conditions different from the nominal ones. We have also performed comparisons of the various linac lattices with different quad configurations in terms of the emittance dilution and further we have compared the TESLA TDR lattice (with two different energy sections) with the US Cold LC lattice (constant energy section).

There are no universally-accepted main linac "decks" available for the ILC and in the absence of these it is generally not possible to generate specifications. Thus, one of the main aims of the LET group is to design linac deck-files which can be used for future simulation studies. This requires an understanding of the dispersive and wake-field contributions to the final emittance dilution and also the sensitivity of a steering algorithm to these contributions. Our plan is to contribute in the design of the main linac lattice file. As a next step, we will perform similar emittance dilution based studies on the optimized lattice as we have been performing on the present one.

Another vital issue is the choice of a steering algorithm for the beam based alignment. Several interesting algorithms have been proposed – like ballistic alignment, Kubo's method, emittance bumps, adaptive alignment etc. None has been studied in an entirely realistic manner, nor has any been studied over the full operating plane of the ILC. We would incorporate different steering algorithms in our simulation code and compare their performance in terms of emittance dilution. An important aspect related with the inclusion of different steering algorithms is to carry out parametric studies on LET hardware to achieve the desired emittance preservation. These studies would be particularly important as they provide information on the requirement of stringency of a given tolerance (for eg. whether some algorithms require much tighter tolerances or better BPM performance than others etc.) as well as to understand the sensitivity of an algorithm to the various systematic effects. Also, in order to move our simulations a step closer to realistic conditions, we would incorporate the effect of ground motion and beam jitter in our studies. In continuation, we would also try to perform multi-bunch studies which have not yet been performed.

(This work is priority 1 as defined by GDE.)

2.1.2 Alignment and Vibration

We propose to undertake an accelerator physics and engineering studies of alignment and vibration issues for the Main Linac. Even though the effect of wakefields on emittance growth is supposed to be small we plan to study how the cryomodule string assembly can be modified to reduce these effects. Some of these studies will aid the 4th generation or Type-IV cryomodule design.

Vibration studies have been carried out for the Illinois site earlier in collaboration with SLAC. We are proposing to systematically study the ground motion at different depths from the surface down to the MINOS tunnel and in the Aurora, IL mine.

(This work is priority 1 as defined by GDE.)

2.1.3 Damping Ring

The number of bunches in a beam pulse from the International Linear Collider would require an unacceptably large damping ring if the linac bunch spacing were also used inside the rings. A long linac bunch interval (340 ns in the TESLA linac design) is likely to be a feature of any L-band superconducting linear accelerator, including the ILC.

The TESLA damping ring bunch spacing was specified as 20 ns, yielding a 17 km circumference for each of the rings. Fast kickers would be used to deflect individual bunches on injection or extraction, leaving the orbits of adjacent bunches undisturbed.

The size of the rings was dictated by the anticipated performance of the kicker: a faster kicker would permit the construction of smaller rings, but the challenges associated with the design and stable operation of a faster pulsed kicker were thought to be daunting at the time the TESLA TDR was written. A number of the kicker designs required the creation of individual pulses of sufficiently short duration so that only one bunch would be influenced by a kicking impulse.

A number of ideas that might allow construction of a faster kicker, and therefore smaller damping rings, have been proposed. Some combination of these may well eliminate the damping ring bunch spacing as the primary constraint on the ring's minimum circumference. As a result, it is appropriate to investigate in some detail an alternative damping ring design which uses a kicker that admits smaller bunch spacing.

Fermilab in collaboration with ANL, Cornell and LBNL have been exploring one particular scheme in which adequate space in the ring is provided for insertion of any one of several possible kickers currently under investigation in the ILC community. In addition, we are studying a kicker design in which the Fourier decomposition of a periodic pulse is used for injection and extraction. Though our studies are still in progress, we are encouraged about the prospects for a smaller ring and feel it is appropriate to summarize our progress at this time.

In our model, the damping ring beam is grouped into 60 bunch trains. Each train consists of 47 bunches spaced by 6.07 ns; a gap separates the tail of each train from the head of the following train. During extraction, the last bunch from each train is ejected in the course of one orbit. As a result, the entire extraction cycle requires 47 orbits. Injection is a time-reversed version of extraction: undamped bunches are delivered to the kicker every 340 ns and are kicked on-orbit as the (new) first bunch in a train.

The lengths of inter-train gaps are chosen to present a bunch that is to be ejected to the kicker every 340 ns. The gap after the last train is slightly longer than the other (identical) inter-train gaps so that the position in a train of the kicked bunch will change after each orbit. The total circumference of a damping ring capable of holding all 2820 bunches is 6.12 km.

These studies suggest the feasibility of a small ILC damping ring are encouraging, but there is a considerable amount of work that remains to be done. In particular, thorough studies of dynamic aperture and kicking techniques will continue. But our results indicate that it is sensible to pursue, for the time being, studies of both the dog bone and small damping rings. It is likely that a kicker that works in a small ring will also work nicely in the dog bone design. Questions of early commissioning of the damping ring are more simply resolved for the smaller rings with their independent tunnels.

Fermilab in collaboration with ANL is now in position to study any ILC Damping Ring design. Fermilab proposes to continue to participate in the Damping Ring design evaluation and cost estimation studies for both the Dog Bone and 6 km ring design. This work has started to be coordinated by ILC GDE and we are participating in subgroups of these activities. We closely collaborate with ANL in these calculations and have asked ANL to lead this effort for FNAL and ANL.

(This work is priority 1 as defined by GDE. But since this includes study of alternate design part of this work is in priority 3. Depending on the guidance from GDE we can focus our resources on either the baseline or alternate design.)

2.1.3 Machine Detector Interface and Energy Deposition Studies

The Energy Deposition Group of Fermilab is collaborating with groups from SLAC, BNL and RHUL in the study of three related issues for the ILC:

- Energy deposition and collimation for design of the beam delivery system and the interaction regions,
- Backgrounds in the detectors and their mitigation,
- Treatment of the spent beams downstream of the interaction points.

During FY05 a MARS15 calculation model was generated including geometry, materials and magnetic fields over 2 kilometers of beam line, including the 1.5-km beam delivery system, the interaction point (IP) and experiments, and the 0.5-km region downstream of the IP for stopping the spent beams. This model is used to study beam impact on accelerator equipment and operation (quenching, cryogenic load, and radiation damage/activation), to the experiments, and to the environment. A preliminary specification for the collimation system was prepared. Initial estimates of experimental backgrounds were studied.

Studies are planned to

- A refinement of the geometric, magnetic, and physic models.
- The first attempt to minimize backgrounds and radiation loads to the experiments and radiation loads to machine components.

The first application of real engineering constraints to the design study and optimizations.

(This work is priority 1 as defined by GDE.)

3.0.0 Conventional Facilities and US Site Development

Goal: Develop US-ILC site near Fermilab by end of FY06.

Fermilab Civil Group is collaborating with SLAC Engineers and soon with Japanese and European engineers to develop methods of analyzing the siting issues and comparing sites. The current effort is not intended to select a potential site, but rather to understand from the beginning how the features of sites will effect the design, performance and cost. The ILC siting and civil construction design is tied to the features of the site. There several key issues that needs to be resolved in close collaboration with accelerator physics and technology groups. Some the key issues are 1) 1 tunnel vs 2 tunnels, 2) deep or shallow layout, 3) Laser straight linac or follow the earth's curvature in segments. GDE ILC design will be done to samples sited in all the three regions. It is proposed that the North American sample site will be near Fermilab. Fermilab and SLAC are working together in development of the site design.

Northern Illinois presents numerous possibilities for the site of the International Linear Collider. Several sites are being explored. Each proposed site has implications that are favorable or less favorable to a successful conventional construction fulfilling the projects requirements. Different sites are conducive to near surface construction methods such as open cut or braced excavation construction while other locations are suitable for deeper rock tunneling construction methods. Proximity to Fermilab, access to power, population density, and environmental impacts are just a few of the many items that need to be considered when choosing a site in addition to cost. The various sites have features that affect initial construction cost, operational costs and ease of technical operations.

Partnering with engineers at SLAC the ILC Conventional Construction team has begun to develop methods of comparing various sites while continuing to refine and document the technical criteria. The current effort is not intended to select a potential site, nor are the sites being examined fixed in its location. In most cases, the siting can be adjusted by miles without substantially changing the pertinent site features. This process is intended to provide insight on the effects that various sites will have. Our current effort is limited to two rock tunnel design solutions and three near surface design solutions. Work continues with geologists at NIU characterizing the geological characteristics of the rock in northern Illinois.

(This work is priority 1 as defined by GDE.)

4.0 ILC Technology R&D

The main focus of the Fermilab ILC R&D is to lead and establish US technical capabilities in the Superconducting Radio Frequency Cavity and Cryomodule technology. The ILC-TRC second report outlined the critical R&D needed for the ILC. Fermilab R&D on the Main Linac is focused to address these issues. The main focus of the R&D efforts will be towards developing the SRF cavity technology to achieve 35 MV/m with a Q of ~0.5e10, ILC cryomodule design, and fully test the basic building blocks of the ILC Main Linac with beam.

The strategic approach we are taking is to involve US industry in the cavity fabrication and to use the existing infrastructure at the collaborating institutes in processing and vertical testing of the cavities to reliably establish ILC level gradients and QsWe propose to begin the development of infrastructure at Fermilab and ANL for High Pressure Water Rinse (HPR), Buffer Chemical Processing (BCP) and Electro Polishing (EP) as these will be needed to perfect the cavity processing technology. We are establishing the capability to assemble these cavities into a clean cavity string and install cavities in cryomodules. Our ultimate goal is to develop a cryomodule design and assembly process suitable for ILC. Our extensive experience with large scale magnet cryomodule technology will play an important role in developing superior designs and lower costs.

The ILC-TRC report gave the highest ranking, R1, to the cavity gradient and performance, “The feasibility demonstration for the ILC requires that a cryomodule be assembled and tested at the design gradient of 35 MV/m in the presence of beam and for long periods. This test should prove that the quench rates and breakdowns, including couplers, are commensurate with the operating expectations. It should be shown that dark currents at the design gradient are manageable, which means several cavities should be assembled together in a cryomodule.”

ILC-TRC ranked the testing of the several ILC Main Linac building blocks with beam as R2. The recommendation stated, “To finalize the design choices and evaluate the reliability issues it is important to fully test the basic building block of the linac. This means several cryomodules installed in their future machine environment, with all auxiliaries running, like pumps, controls etc. This test should as much as possible simulate the realistic machine operating conditions, with the proposed klystron, power distribution system and with beam. The cavities must be equipped with their final HOM couplers. The cavity relative alignment must be shown to be within requirements. The cryomodules must be run at or above their nominal field for long enough periods to realistically evaluate their quench and breakdown rates.”

The cost of the main linac is about one-half the total ILC cost, of which a major fraction is the cryomodule cost. In order to best estimate the cost of the cryomdoule we think it is essential to build one or two modules with the SMTF collaboration working closely with industry. The first few cryomodules cannot be made solely in industry because they do not have the experience. However, the model we are pursuing is the construction of the cryomodule by "teaming" with industry. To summarize, we propose that the cryomodule construction needs to be funded in FY06 in order to best estimate its cost for the ILC RDR. The goals are to fabricate 35 MV/m cryomodule with industry to achieve a credible cost estimate.

Goal: A complete ILC RF unit operating with beam in the ILC pattern, at 35 MV/m by the end of FY09 as described in the SMTF proposal. This will answer the crucial R&D, design, cost etc. issues for ILC.

Deliverable: The Fermilab ILC SRF R&D program deliverables are defined with relative priorities:

- Priority 1
  - Cavity technology to routinely achieve $\geq$35 MV/m and Q ~0.5-1e10.
  - ILC Cryomodule with final design and cost reduction features.
  - Fully tested basic building blocks of the Main ILC Linac. Evaluate the reliability issues. Finalize design choices in collaboration with GDE.
- Priority 2
  - RF controls and LLRF System for ILC
  - Instrumentation development
  - Enhance interaction with industry and Cavity & Cryomodule Technology transfer to Industry.
- Priority 3
  - Production Testing: US Manufacturing development and testing center
  - High gradient cavity development
    - Reentrant and Low Loss Cavity
    - Single Crystal Cavity

4.1 SCRF Cavity and Cryomodule Development and Testing

The ILC Main Linac design plans to use 1.3 GHz superconducting cavities. The performance goals of these cavities are >35 MV/m and Q ~0.5e10. At present much of the expertise of producing and testing these cavities are in Europe and Asia.

At present cavity fabrication R&D is taking place at DESY, KEK and Fermilab. Although DESY is the world leader in cavity technology its focus is on achieving ~28 MV/m for the XFEL project. The focus of the TTF at DESY is now on operation with a rather limited time available for ILC related studies and development. KEK has also proposed to build a Superconducting RF Test Facility (STF) with R&D focusing on a new design of the ILC cryomodule with the cavities planned to achieve ~45 MV/m. The main goal of Fermilab R&D is to develop US capabilities in fabricatingand operating with beam ~35 MV/m and high Q ~0.5e10 SRF cavities and cryomodule. The focus is to address the R1 and R2 issues with the present ILC 1.3 GHz cavity design, while taking into account new developments from around the world. We plan to collaborate witlh all major SRF centers in the US ,Cornell, Jlab, LANL, ANL, as well as DESY, INFN and KEK abroad. Our SMTF collaboration is already on a sound footing and many activities are underway. Substantial support will be needed in the coming years to sustain the collaboration and its essential activities.

Fermilab has proposed to carry out a collaborative R&D with US laboratories, industries and our international collaborators to produce ILC quality cavities in the US. The collaborative effort is discussed in depththe proposal submitted to Fermilab by the SMTF collaboration.This proposal was reviewed by the Fermilab Director's Advisory Committee and found strong support for its goals. The US ILC Main Linac responsibilities have been divided between Fermilab and SLAC. Fermilab has the responsibility of the Main Linac superconducting part and RF controls. Fermilab would also coordinate this work with the collaborating ILC institutions under the SMTF umbrella. SLAC has the responsibilities of the Main Linac RF power.

Fiscal Year (05-06) Break down of the Main Linac R&D deliverables

- FY05: Cavity and Cryomodule
  - Order 12 1.3 GHz cavities. Begin to build US infrastructure for cavity fabrication (along with developing Industrial infrastructure and partners), processing and testing. Order all the ancillary components (helium vessels, input couplers, tuners, assembly and alignment tools, etc) for the first cavity string. Complete fabrication of Horizontal Test Dewars (HTD) for fully dressed cavities. Start fabrication of clean string assembly and Cryomodule Assembly Facility at Fermilab. Develop cost reduction methods for assembly.

- FY06: Cavity and Cryomodule
  - Order 24 1.3 GHz Cavities for "Tight Loop" Production and "Tight Loop: Processing (from 2 US vendors). (The phrase "tight loop" is intended to convey the importance of establishing a reliability in the process and production sequences.)
  - Receive 8 dressed cavities from DESY for 2nd cryomodule fabrication.
  - Finish fabrication of the 1st Cryomodule (TTF3 type).
  - Start design of the 4th Generation ILC cryomodule. It is anticipated that the 3rd cryomodule to be built in US will be a 4th generation.
  - (We anticipate that the 4th generation module will have all the essential features of an ILC cryomodule, including cost reduction features in design and assembly. To establish this generation on a sound footing will need considerable design, engineering and prototyping efforts.)

- FY05: RF Power
  - One 5 MWatt klystron to support a 1.3 GHz 8 cavity cryomodule.
  - 1 Small modulator to support a 300 kWatt klystron for the 25 MV/m single cavity
  - 1 large modulator to support 5 MWatt klystron for a 8 cavity cryomodule.

- FY06: RF Power (Additional RF power is expected from SLAC)

– 1 10 MWatt klystron to support an RF unit

– Finish the modulator started in FY06 to support a 10 MWatt klystron.

We will develop infrastructure to fabricate the aforementioned hardware.

(This work described in section 3.1 and subsections (3.1.1- 3.1.3) is priority 1 as defined by GDE. We view this work as in support of the TDR. Fermilab views this effort as priority 1 as this technology needs to be developed and perfected in US laboratories. We are working towards involving and developing US industry for ILC. GDE with its guidance may put this in priority 2 as these are also R&D in support of critical baseline components and systems.)

4.1.1 1.3 GHz Cavity Development

Goal: The 1.3 GHz cavity fabrication program at Fermilab is designed to deliver a cavity fabrication technology to reliably and cost effectively produce cavities with a gradient of 35 MV/m by the end of FY08.

In FY05, we started the fabrication of the 1.3 GHz cavities. We are using the TESLA Technology Collaboration (TTC) design of the cavities, HOM, blade tuners, couplers, helium vessel and vacuum vessel. The TTC drawings have been converted for US vendors. In FY05, we have placed an order for 8 cavities, 4 each from AES and ACCEL. We will also receive 4 bare cavities of Low Loss design from KEK under US-Japan agreement. We also plan to receive four 9-cell cavities from DESY in FY05. These cavities are ~25 MV/m cavities and will be used for infrastructure development. These cavities will be used to make the tooling for BCP and EP at LEPP and Jlab respectively.

<u>Development of US Capability in 1.3 GHz Cavity Processing:</u>

At present Fermilab does not have either BCP or EP facilities. We are in the process of establishing MOUs with LEPP, Cornell and Jlab for processing and vertical testing of the cavities that were ordeded in FY05. AES and SMTF collaborators will work with LEPP in learning the BCP and vertical testing process. The contract is being setup to transfer the technology to AES. As full participants, Fermilab personnel will undergo intensive training in all procedures. A similar discussion of technology transfer is needed with ACCEL.

Jlab will develop tooling for the EP and vertical testing of these cavities. We will also use the Jlab EP facility to develop the EP parameters to achieve 35 MV/m. Jlab will also dress these cavities and then ship to Fermilab for horizontal testing, string and cryomodule assembly. We have started this work in FY05 but a significant fraction of this work will take place in FY06.

We are signing an MOU with DESY to receive 8 (+ a few spare) dressed 1.3 GHz cavities in exchange of 4 dressed 3.9 GHz cavities in a custom Fermilab designed and fabricated cryomodule. These cavities are expected to arrive by June 2006. It is expected that we would have at least 16 fully tested and dressed cavities by June 06 for the fabrication of the 2 cryomodules (to be discussed later) in the US. These cavities would establish the initial US 1.3 GHz cavity fabrication and processing capabilities. This will be used to develop Tight Loop Processing parameters, while we develop the processing infrastructure at FNAL/ANL. This minimal investment will also allow US industry, physicists and engineers to gain valuable experience in 1.3 GHz cavity fabrication and processing and cryomodule fabrication.

Tight Loop Production and Processing of Cavities:

In parallel we will continue work on perfecting the high gradient technology (Tight Loop Production and Processing) in FY06. The plan is to fabricate cavities using US industries. The cavity processing, BCP, EP and HPR is planned to take place at FNAL/ANL facility located at ANL. This process will certify the process from Nb to cavities including the infrastructure at US industries. Our plan is to perfect the processing technology in two steps, first the BCP and then the EP with the goal to reliably achieve 35 MV/m and Q of ~0.5e10 by end of FY08. This schedule is essentially driven by the availability of EP facility. We propose to build and process 24 cavities in FY06 to achieve a processing and testing rate of 2-3 cavities/month by the end of FY06. A new BCP system (3.9 and 1.3 GHz) was built at Fermilab and is being relocated at ANL. It is expected to be operational by early FY06. We need to build a tooling fixture for BCP of 1.3 GHz cavities in this facility. We have started discussion with LANL in collaborating on EP development at Fermilab/ANL facility. This will be done in collaboration with KEK, DESY and Jlab. We plan to design and start construction of an EP system in FY06 with a goal of operation in early FY07. We have also started discussion with ANL in upgrading their EP system for ILC use. A decision on an EP system will be made shortly when all possible paths have been evaluated.

(This work is priority 2 as defined by GDE. Fermilab views this effort as priority 1 as this technology needs to be developed and perfected in the US and we also need to involve and develop US industry.)

4.1.2 ILC Cryomodule design and fabrication

Goal: Assemble the first US cryomodule (Type III+) at Fermilab. Design and construction of ILC Cryomodule including cost reduction and US industrial participation.

In FY05 we have converted all the DESY drawing in the US system so that we can place an order to US vendors. The goal for FY06 is to assemble the first US cryomodule at Fermilab. This first cryomodule is planned to be the Type-III+. We expect to have enough cavities in FY06 to build a second cryomodule. The design and type of the second US assembled cryomodule is under discussion. The decision will be based on details of the proposed design changes for the next generation ILC cryomodule. If we could assemble a 2nd cryomodule by early CY07 it would complete the Phase 1 of the SMTF proposal and will allow us to operate the modulator, klystron, rf distribution, and controls at full power. We plan to start the design work on the (next) 4th generation cryomodule in late FY05, after Snowmass, in collaboration with INFN with a goal to start procurement in late FY06.

The ILC cryomodule design is expected to evolve for next several years. We are leading this discussion with ILC collaborators, including DESY, INFN and KEK.

(This work is priority 2 as defined by GDE. Fermilab view this effort as priority 1 as this technology needs to be developed and perfected in US and we also need to involve and develop US industry.)

4.1.3 Cavity and Cryomodule fabrication and testing infrastructure

Goal: Establish a facility to handle processed cavities, HPR, string assembly and fabrication of cryomodule. We propose to have this facility ready by June 06 to handle cavities coming from several sources.

Fermilab and SMTF collaborating institutions have considerable infrastructure in SCRF cavity development. Nevertheless substantial upgrades of these facilities are needed in order to develop state-of-the-art cavities and to establish reliable processing protocols. This plan is described in detail in the SMTF proposal.

In FY05, we have developed a plan to consolidate all of Fermilab SCRF cavity and cryomodule fabrication facility (CAF) at MP9. Significant investment in FY05 has been made in building this infrastructure. This facility is expected to be operational in FY06.

There is no 1.3 GHz Horizontal Test Dewar (HTD) is the US. This has been used to test a cavity fully dressed with He-vessel, couplers and tuners and tested with full RF power. Once a cavity passes this test it is ready for the string assembly. Fermilab has initiated a design of a HTD based on the CHECHIA design from INFN. The parts for the HTD will be procured in early FY06 for it to be operational in mid FY06. These single cavity test stands will be located in the Meson East building as the cryogenic infrastructure can be easily and cost effectively made available there.

Initially we plan to use the vertical test stands at Cornell and Jlab for the bare cavity testing. We are developing plans to build a vertical test stand at Fermilab to support the “Tight Loop Production” cavity fabrication process. This would be built in the later part of FY06.

(This work is priority 2 as defined by GDE. This work is needed to support the projects described in the previous two subsections. The Fermilab view is that this should be considered as priority 1.)

4.2.1 RF Power

Goal: Power two 8 cavities cryomodule by the end of CY06. Also power the Horizontal (early FY06) and Vertical Test Stands (end of FY06).

Fermilab in collaboration with TESLA collaboration has helped in the development of the RF Power and its distribution system at TTF. The modulators, design by Fermilab engineers, are being produced by industry. We are not proposing to undertake any R&D in this area as we expect SLAC to take a leadership role in RF power generation for the US. We will build and/or acquire from industry to support Fermilab R&D program.

Modulator and Klystron

Several modulators and klystrons will be needed for the operation of these cryomodule and test stands. We propose to build the first modulator at Fermilab while we purchase klystrons from the industry. We anticipate that SLAC will take a lead in this after the FY06 purchase. Several klystrons and modulators are being rebuilt in FY05 for use at SMTF. This work will continue in FY06.

A 300 kWatt klystron and new small modulator is needed to power the 25 MV/m single cavity module we plan to install in A0. Similar pairs will be needed for the horizontal and vertical test stands. We need a 5 MWatt modulator and klystron to power the first eight-cavity cryomodule.

In FY06 we propose to purchase one 10 MWatt klystron. The modulator being built in FY05 will be sufficient to power the 10 MWatt klystron.

(This work is priority 2 as defined by GDE and is needed to support the cavity and cryomodule work.)

LLRF Controls

Goal: Develop an ILC LLRF controls.

Fermilab, the University of Pennsylvania, and INFN (Pisa) is proposing to develop a LLRF control system for the ILC. Collaboration with DESY, KEK, and SLAC is being discussed. It is proposed that this R&D will be first used and developed at the vertical and horizontal test stands and cryomodule test facility. The key of the ILC design is to power 24/36 cavities with one set of a modulator and klystron. DESY TTF uses a similar LLRF system. We are developing a specification and design of the ILC LLRF system in collaboration with DESY, KEK, Cornell, and SNS. The design specification and R&D plan will be reviewed in late fall in 05.

(This work is priority 1 as defined by GDE since this is to support the baseline design and TDR. GDE could also put this in priority 2 as it is required for the cavity and cryomodule development.)

4.3.0 High Power Test Facility (HPTF)

Goal: Provide infrastructure to test single cavity in horizontal and vertical test stands. Build facility with support infrastructures to test ILC cryomodules at high power with beam.

High Power Test Facility (HPTF) is a high-power testing subset of a national superconducting RF R&D effort. It will be located at Fermilab mainly at two locations. The single cavity horizontal and vertical test stands will be located in the Meson Detector Building to take advantage of the available cryogenics. The ILC cryomodule and beam test will be in the New Muon Lab (NML) to take advantage of the excellent space and radiation protection. HPTF is designed to supply infrastructure including space, power and other utilities, controls, radiation shielding etc. for complete high-power tests.

At the NML a temporary cryogenic system will be installed to meet the schedule. We are evaluating two options: 1) Dewar or tanker-supplied helium and a gas recovery system in Lab B, 2) a satellite refrigerator at NML and compressors at Lab B. A decision will be made by end of summer FY05.

At the Meson Lab the high priority work is to get the cryogenic system commissioned in FY05. This will be made operational by testing the Capture Cavity in Oct. 05 at 4.5 K. An upgrade to the cryogenic vacuum system would be required to achieve 2 K. The goal is to first test the capture cavity at 2 K (Feb. 06) and install and operate the Horizontal Test Dewar (April 06). The RF and controls could be common for both the test setup. We are developing plans to design and install a vertical test stand at Fermilab for 1.3 GHz cavities test. The plan for HPTF at Meson is to have enough capacity to test the 1st US assembled ILC cryomodule with RF by Jan 07.

At the NML we are getting ready to remove the Chicago Cyclotron Magnet in FY05 and get the building infrastructure ready for the test area. The present plan is to move the Electron Source to NML in the summer of FY06 and install all the new components developed and tested in FY05 at that time. This will give us considerable cost and schedule benefits. It is expected that the first US Assembled ILC cryomodule will be installed for testing with RF and beam at NML in spring of FY07.

The NML tunnel will require a small extension to accommodate four ILC cryomodules with the electron source. A plan is being developed and work could be carried out in FY07-08 as this does not impact the planned operation.

The new refrigerator and cryogenic system required is described in the cryogenic section.

(This work is priority 4 as defined by GDE. Fermilab's view is that this is priority 1 as this is required for TDR and priority 2 as this R&D is in support of critical baseline components and systems)

4.4.0 Cryogenics

Goal: 1) Provide cryogenics for the Horizontal and Vertical test stand by end of 2005. 2) Provide a temporary solution for cryogenics at NML to cool down the electron source and 2 ILC cryomodule for test with beam by end of CY06 and 3) Design and build a new cryogenic system by end of FY08-09.

The cryogenic Test Facility (CTF) refrigerator system at Meson building at Fermilab will be used to supply initial helium for the test facilities. It is expected that the system will be capable of ~60 Watts at 2K after its upgrade. The upgrade has started in FY05 and it is expected to be operational to provide 4.5 K liquid helium for the Capture Cavity test by the end of FY05. Further upgrades will be performed in early FY06 to make this facility operational at 2 K.

Fermilab plans to locate the ILC cryomodule test facility with beam in the New Muon Laboratory (NML). This building does not have cryogenics available. Design of a temporary cryogenic system is underway to supply enough cryogenics for the test of the first two cryomodules with the electron source. A temporary cryogenic system will be installed in FY06 to meet the schedule. We are evaluating two options: 1) Dewar or tanker-supplied helium and a gas recovery system in Lab B, 2) a satellite refrigerator at NML and compressors at Lab B. A decision will be made by end of summer FY05 and work will continue into FY06. The goal is to have the system ready for operation by end of FY06.

The capacity of the Meson and temporary refrigeration system will not be adequate for ILC tests as proposed in the SMTF proposal. A new system with 300-600 Watt capacity (at 2 degrees K) will be needed. We are investigating two possibilities 1) refurbish and use the SSC Cryogenic system stored at ANL or 2) purchase a new system. A technical review committee is evaluating these options and a recommendation is expected later in FY05. The goal is to have a large capacity system operational ASAP at a minimal cost. This is a long lead item requiring considerable resources in FY06.

(This work is priority 2 as defined by GDE. Considering that this is a long lead item and this will support the work for the TDR it should get priority 1.)

4.5.0 Electron Source for ILC Cryomodule Testing.

Goal: 1) Provide electron beam for cryomodule testing by end of FY06. 2) Upgrade the injector to provide ILC quality beam.

As described in the SMTF proposal we propose to use the Fermilab NICADD photo-injector (FNPL) as an electron source for testing the cryomodule. In FY05 we have acquired the 25 MV/m capture cavity from DESY, 3.9 GHz accelerating cavity and associated RF power for the FNPL upgrade, this work may continue in FY06. But for this budget exercise we are assuming that cavities and RF power are not part of the work. All of these new components will be installed with the FNPL when it is moved to the New

Muon Lab around Summer 06. Further upgrades of the FNPL will be required to match its beam qualities to that of ILC for the beam studies at SMTF. All the hardware needed for the Injector Phase B upgrade has been allocated in FY05. The major expense will be in relocating the FNPL to the New Muon Lab and commissioning. In FY06 we plan to upgrade the FNPL electron source to match the ILC beam parameters.

The table compares the present FNPL parameter to that of ILC.

Parameters	units	Requirement ILC/SMTF	Achieved at FNPL/A0 (06/2005)
RF Pulse Length	msec	1.5	0.5
Pulse Rate	Hz	5	1
Beam Pulse Length	msec	1.0	0.5
Electrons per Bunch		2e10	1e11
Bunch Spacing	Ns	337	1000
Charge stability	%	5 (rms)	5 (rms)

Required parameters for ILC/SMTF versus achieved parameter at FNPL/A0. (red: not achieved, green achieved, black: no problem to achieve but not yet tested)

Present limitations of FNPL (as of June 2005):

Since the SMTF EOI was submitted, a new photocathode-drive laser oscillator was procured and the charge fluctuation now matches the ILC/SMTF requirements[1]. The laser, in its present configuration, can in principle provide bunch trains with repetition rate of 3 MHz; test will be done soon.

The main limitations are coming from the rf hardware:

- L1: The rf-pulse on the rf-gun is limited to 0.6 msec
- L2: The rf-pulse rate is limited to 5 Hz
- L3: There are significant doubts that the rf-gun will withstand the 1 ms / 5 Hz rf format, the rf-gun seems to be limited to about 0.2 msec due to vacuum breakdown

The proposed upgrade plan

- L1&L2: require modification of the PFN + current transformer.
- L3: A **new rf-gun** should be designed. A path would be to copy the cylindrical-symmetric rf-gun, designed at DESY, which is successfully operated at the TTF

[1] Measurements/monitoring being done at FNPL/A0 since June 17, 2005

VUV FEL in DESY with TESLA TDR parameters. BESSY in Berlin has been working on improving the DESY-design and we should benefit from their R&D.

We need provision for general beamline hardware (vacuum pump, screens, BPM, ICT, vacuum parts, magnets); approximately 10 meters of beam line will be needed in addition to what we have at A0 (since in phase A the rf-gun will be located 28 m upstream from the TESLA-module).

- A new optical table (18'x4') should be procured before we move to SMTF. This will enable the entire laser to fit on a single table and reduce jitter due to vibrations.

- The photocathode drive-laser is one of the most critical components of FNPL. It was built by University of Rochester in 1995 and needs to be upgraded. Recently it was partially upgraded (new seed oscillator) and the performance was enhanced (charge stability is now < 5 %). We should have provision to continue this upgrade, and we would like to eventually upgrade the amplification scheme to include diode-pumped amplifiers to replace the multi-pass and two-pass amplifiers. If we could do the upgrade while moving A0 to SMTF, the laser system will not need water cooling (since diode-pumped amplifier/oscillator are air-cooled). The upgrade could be:
    - Upgrade multi-pass amplifier to diode-pumped
    - Upgrade 2 two-pass amplifiers to diode-pumped

(This work is priority 4 as defined by GDE. Most of the other electron source development has taken place in FY05. The source can be used as it will be in mid FY06 in the initial phase of ILC R&D at HPTF.)

4.6.0 Instrumentation and Controls for ILC

Goal: Start participation (and plan to lead in a few areas) ILC instrumentation and controls.

Fermilab proposes to put together a small team of physicists and engineers to work on the specification and design of the Instrumentation, Controls and feed-back system for the ILC. Fermilab with its experience with large accelerator complex, two large detectors at Fermilab, development of LHC remote control room and analysis center, Grid computing, etc is positioned to contributed significantly in the Controls and DAQ for the ILC accelerator. This effort will evolve in FY06 as we better understand the scope of these projects. At present Controls development is being done in support of the cavity and cryomodule test facilities. We plan to use EPICS as the control system but it is anticipated that a state of the art control system will be needed for the ILC.

(This work should be priority 1 as defined by GDE.)

5.0 U.S. Industry Consortium For The International Linear Collider (USICILC)

Goal: Get US industry involved in an organized fashion to participate in ILC technology development, technology transfer and support of the project.

Fermilab in collaboration with other US laboratories have been leading a discussion in forming a U.S. Industry Consortium for the International Linear Collider (USICILC). Similar forums exist in Asia and Europe led by their major laboratories KEK and DESY respectively. Fermilab initiated this discussion with the industry we already work with on our R&D projects. Initial discussion among industry has been very encouraging. We view this industrial consortium to be an independent organization that will need technical, public and government relation information from the ILC.

U.S. R&D in support of the ILC has been Government funded and led by various DOE National Laboratories at relatively low funding levels. There has been limited support by U.S. industry for these efforts since these activities were primarily studies and laboratory experiments to optimize the performance parameters of the machine. As the ILC design progresses, there will be an increasing need for communication and technology transfer between the industrial base of the U.S. and the American Regional Team (ART) to the GDE. Therefore the goals of the USICILC are:

- Identify and evaluate issues associated with the ILC and its U.S. industrial support base and develop consensus on critical topics;

- Educate the public and private sectors by providing information on ICILC positions to the Congress, the Department of Energy, other appropriate agencies, education, science, and labor communities and the ART;

- Assist the Administration and DOE, together with Congressional supporters, to ensure the continuity of funding for the ILC from R&D through construction and operation on a timely basis.

Objectives: Specific objectives for the ICILC to meet these goals are:

- Provide a forum for U.S. industry members to interact with the ART through meetings, workshops, electronic communication and by other means;

- Provide its U.S. industry members with background materials on the objectives, status and current progress of the ILC international program and the U.S. participation therein;

- Communicate U.S. industry's key issues concerning technology transfer and risks, fair and open competition, manufacturing and production issues, and infrastructure limitations impacting the fair and unbiased participation of U.S. industry in the ILC program;

- Provide an open forum for the U.S. industry's experience to be communicated to and accessed by the ILC international design group; and

- Identify critical issues that potentially impact U.S. industry's participation in the ILC program.

The cost of this effort is getting industry to do the ILC work from the start. This could result in some duplication of infrastructure at laboratories and industry. At this stage of the ILC we do not anticipate industry to put a significant amount of infrastructure upfront.

(This work is priority 1 although not defined by GDE. The Fermilab view is that getting a broad base of industrial involvement in the ILC is important for cost reduction, industrial fabrication and schedule. This should be done at a very early stage.)

6.0 Collaboration and Outreach

Goal: Communication and education on ILC.

The International Linear Collider is among the largest scientific projects ever contemplated. It will require support from a broader group of people. Fermilab has formed an outreach committee to develop and implement an ILC outreach program to support the ILC. Fermilab has become a leader in ILC outreach activities. We are working with our SLAC, collaborating universities and government. The outreach activity will be directed to several different constituencies, including

- The Federal government, including both the Congress and the Executive Branch
- The Illinois State Government
- The High Energy Physics Community
- The scientific community beyond high energy physics
- Local universities, businesses and laboratories
- The communities nearby the Linear Collider site and Fermilab
- The broad public, especially young people.
- US ILC Industrial Forum

(This work is priority 1 but is not defined by GDE.)